

TITLE OF THE INVENTION

VARIABLE SAMPLE RATE RECURSIVE DIGITAL FILTER

BACKGROUND OF THE INVENTION

5 The present invention relates to digital filtering, and more particularly to a variable sample rate recursive digital filter that maintains a constant frequency response over a range of sample rates.

10 A problem that is common to several signal processing applications, such as sampling rate conversion, jitter/wander compensation and/or measurement, picture quality measurement and the like, is trying to maintain a constant frequency response over a range of sample rates. In picture quality measurement based on human vision models where test and reference video sequences are viewed with different formats, displays (frame rates, spatial resolutions) and viewing distances (different spatial sample rates within the field of view for the human eye), it is important to maintain both efficiency and accuracy. Maintaining the spatial and temporal frequency response of an adaptive filter, such as that described in co-pending U.S. Patent Application Serial No. 09/858,775 filed May 16, 2001, allows one to simulate the perceptual difference between viewing a video sequence close to a display (i.e., two screen heights) and far away (i.e., 10 screen heights) without the need for re-sampling, for example.

25 Prior methods require either re-sampling or re-calibration of the human vision model. Calibration may be very time consuming, so it is not desirable to calibrate for every distinct viewing distance. Re-sampling involves re-sampling the data twice, once for the input to the human vision model and

then for the intermediate human vision model image just prior to calculations involving both reference and test video (differencing). This requires extra processing and introduces interpolation inaccuracies.

What is desired is a variable sample rate recursive digital filter that
5 maintains a constant frequency response over a range of sample rates without requiring re-sampling or re-calibration for each new sample rate.

BRIEF SUMMARY OF THE INVENTION

Accordingly the present invention provides a variable sample rate
10 recursive digital filter that changes filter coefficients of an adaptive digital filter according to respective equivalent sample rates. The adaptive digital filter is calibrated initially for a specific sample rate which determines specific filter coefficients to be used. When the sample rate is changed, a ratio is
15 determined between the calibrated or initial sample rate and the new sample rate and from the ratio a coefficient factor is calculated. The coefficient factor is used to modify the initial filter coefficients for the calibrated sample rate to produce new coefficients for the new sample rate. The new coefficients are applied to the adaptive digital filter to provide the desired signal processing without requiring re-sampling or re-calibration and without changing the
20 frequency response.

The objects, advantages and other novel features of the present invention are apparent from the following detailed description when read in conjunction with the appended claims and attached drawing figure.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

Fig. 1 is a block diagram view of a human vision model based picture quality metric apparatus incorporating variable sample rate recursive digital filters according to the present invention.

5 Fig. 2 is a block diagram view of a variable equivalent sample rate coefficient converter for the variable sample rate recursive digital filters according to the present invention.

10 Fig. 3 is a graph diagram view illustrating the constant frequency response of the variable sample rate recursive digital filters at different sample rates according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1 a human vision model based picture quality metric apparatus **10**, shown as an example of a signal processing apparatus using variable sample rate recursive digital filters, has as inputs a reference video sequence and a test (degraded) video sequence. The video sequences are stored and displayed on respective display devices **12, 14**, and processed by a human vision model **16**. Each channel, reference and test, is processed initially by adaptive digital filters **18, 20**, as described in the above-referenced pending U.S. Patent Application, before being processed by the remaining model components **22** to provide a picture quality metric output. Each digital filter **18, 20** has equivalent viewing distance or spatial sample rate and frame rate or temporal sample rate controllers **24, 26** that

provide variable coefficients to the digital filters to independently tune them to particular viewing distance and/or frame sample rates.

The control signals, or new coefficients, for the digital filters 18, 20 to give the equivalent response of re-sampling both the input and output are derived from taking the ratio of bilinear transforms at respective sample rates. Traditionally a bilinear transform B converts the filter poles in the z-domain (spatial) to the s-domain (frequency) where the sample rate changes are linear. The pole in the s-domain is multiplied by a sample rate ratio and then converted back to the z-domain.

$$B\{P_z\} \rightarrow P_s; \quad B^{-1}\{P_s * R\} \rightarrow P'_z = K * P_z$$

where B is the bilinear transform, P_z is the filter pole in the z-domain, P_s is the transformed filter pole in the s-domain, R is the ratio of the initial and new sample rates, K is a constant or zFactor, and P'_z is the new filter pole transformed back to the z-domain.

Given an initial or calibrated sample rate and a corresponding filter coefficient, the new filter coefficient for the new sample rate is obtained by multiplying the initial filter coefficient by K or zFactor determined as follows:

$$zFactor(z, R) := (1/z) \{ (z(1+R) + (1-R)) / (z(1-R) + (1+R)) \}$$

where z = initial z-domain coefficient and R = ratio of sample rates (old/new).

This equation is illustrated by Fig. 2 and may be implemented in hardware or in software.

Consider a recursive, first order, difference equation for a filter of the form:

$$y_{n+1} := y_n + c(x_n - y_n); \quad y_n = y_{n-1} + c(x_{n-1} - y_{n-1}) = (1-c)y_{n-1} + cx_{n-1}.$$

The Z-transform of the equation is:

$$H(z,c) := c/(z-1+c)$$

If DC gain is held to unity: $c/(1-1+c) = 1$; then $z=1$ and $H(z,c) = 1$ and the filter has a pole at $(1-c)$, i.e., for $c = 0.3$, pole = 0.7.

5 The frequency response is given by:

$$F(c,\omega) := H(e^{-j\omega},c) \text{ and } \omega_n = \pi(n/N) \text{ where } n/N \text{ varies between 0 and 1.}$$

The following is an example matching a filter composite frequency response after temporal resampling based on the bilinear transform. The illustrative filter is a bandpass filter generated from the difference between two lowpass filters. If the initial sample rate T_0 is 1/60 and the respective lowpass filter coefficients are $C_{ts0} = 0.6$ and $C_{tc0} = 0.48$, then when the rate changes to $T_1 = 1/24$ the ratio R becomes 0.4, i.e., $T_0/T_1 = (1/60)/(1/24) = 24/60 = 0.4$. Then the new coefficients become $C_{ts1} := zFactor(C_{ts0},R)*C_{ts0}$ and $C_{tc1} := zFactor(C_{tc0},R)*C_{tc0}$, i.e., $C_{ts1} = 0.818$ and $C_{tc1} = 0.754$. The new sample rate $\omega_1 = \omega_0 * R$. The frequency response of the bandpass filter is then given by $F_{t0}(\omega) := |F(C_{tc0},\omega)^2 - F(C_{ts0},\omega)^2|$ for the initial sample rate and $F_{t1}(\omega) := |F(C_{tc1},\omega)^2 - F(C_{ts1},\omega)^2|$ for the new sample rate. When scaled appropriately and plotted together as shown in Fig. 3, where the solid line is the frequency response of the composite filter at the initial sample rate and the dotted line is the frequency response of the composite filter at the new sample rate, it is apparent that using the bilinear transform provides the desired constant frequency response result for the filter.

Thus the present invention provides a variable sample rate recursive digital filter by using a bilinear transform to determine a coefficient factor as a

function of an initial coefficient and a ratio of an initial sample rate and a new sample rate, the coefficient factor being used to adjust the initial coefficient for the new sample rate so that when applied to the variable sample rate recursive digital filter the frequency response at the different sample rates is constant.

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constant.